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SOLID ROCKET MOTOR CONTAINED BURN DISPOSAL STATUS

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Abstract

Obsolete, excess or aged solid rocket motors are being stockpiled or destroyed at an increasing rate. The existing method of destroying solid rocket motors is through a process called open burn or open detonation. Open burning or open detonation of solid rocket motors is coming under greater environmental scrutiny and governmental regulation. In response to the demand for an environmentally responsible solid rocket motor disposal process Lockheed Martin (LM) initiated an effort in 1988 to identify and evaluate alternate solid rocket motor disposal methods. During the initial study, many potential disposal processes were identified and four were thoroughly evaluated. The contained burning process was judged to be the safest, most cost effective, and mature technique applicable to both Class 1.1 and Class 1.3 solid propellants. The contained burn process involves firing a nozzleless solid rocket motor inside of a containment vessel. The contained burn process confines and cools the combustion products and subsequently treats the effluent gases, liquids and solids, utilizing standard industrial treatment technologies. This process has been demonstrated repeatedly at a full scale test facility and now represents a mature technology for the safe and environmentally responsible destruction of solid rocket motors.

Background

In 1989, the U.S. Navy Strategic Systems Programs (SSP) tasked LM to identify and evaluate alternative solid rocket motor disposal methods to that of open burn or open detonation. Solid rocket motors from aged cold war defense systems as well as decommissioned motors resulting from recent international arms treaties are being stockpiled and destroyed at an increasing rate. Storage of obsolete, excess, or aged solid rocket motors is not it a permanent solution and, in some cases, may present safety concerns. Open burn and open detonation is presently the only option for the disposition of solid rocket motors. Increasing pressure from surrounding communities, environmental advocate groups, and government legislation is forcing the development of safe and reliable alternatives to open burn/open detonation.

In the LM study, four potential disposal processes were thoroughly evaluated: 1) contained burn and 2-4) propellant removal followed by incineration, ingredient recovery, or bioremediation. Of these processes, contained burn was the method of choice as it was projected to be the only one capable of safely disposing of solid rocket motors

containing either Class 1.1 or Class 1.3 propellants. It also requires the least number of handling steps by personnel, making it an inherently safer operating design.

At the direction of the U.S. Navy, LM initiated a development program to study the feasibility of the contained burn process for the disposition of Fleet Ballistic Missile solid rocket motors. The program has progressed from laboratory evaluations to full scale demonstrations of the contained burn process and has produced a conceptual design for a full scale production facility. The laboratory evaluations of the contained burn process (1-40 gm. propellant samples) demonstrated that all propellant is consumed during low pressure combustion and identified the major combustion products. The design, construction and operation of a sub scale (80-300 pounds of propellant) pilot plant capable of treating the rocket motor combustion gas stream established the efficacy of the contained burn process. A firing chamber was designed and built to demonstrate the combustion of full scale solid rocket motors (4,000-20,000 pounds propellant) in a confined chamber, Figure 1. During the course of 10 successful tests, a thermal management system for cooling the rocket motor exhaust was optimized and combustion products for full scale motors were identified. Finally, a gas and particulate treatment system was added to the full scale firing chamber, providing the capability for a comprehensive process demonstration. The full scale process test facility, Figure 2, has successfully demonstrated the complete contained burn process. Low pressure combustion of four full scale fleet ballistic solid rocket motors in the confined firing chamber followed by the successful treatment of the combustion products has been demonstrated. The

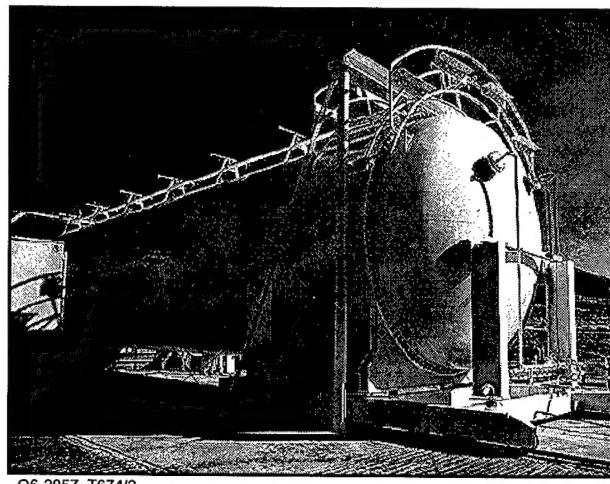


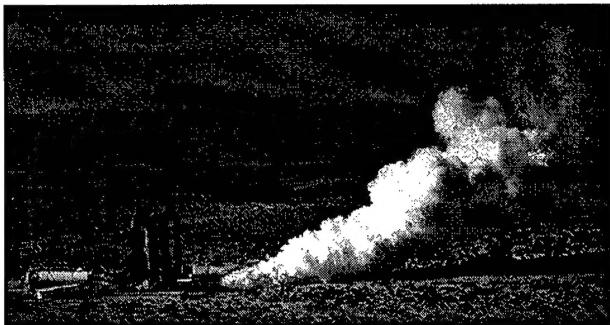
Figure 1 Full scale contained burn firing chamber

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Figure 2 Full scale contained burn with treatment is a proven technology for class 1.1 propellant

treatment efficiencies for the particulate and acid gases exceeded design specifications.

A conceptual design for a contained burn facility capable of the disposition of FBM solid rocket motors has been developed using information and data obtained during the development program. The facility design includes site layout, energy and mass balances, process flow diagrams, quantity distance relationships, required utilities, motor firing systems, process fluids treatment systems, solids recovery methods, and emissions monitoring. The facility is capable of the disposition of the Trident I (C4) inventory, Table 1, at a rate of one motor per day, 5 motors per week. The facility design can be modified for the disposition of Trident II (D5) inventory if required, Table 2.

Table 1
C4 Motor Inventory for Disposal

Motor Type	Number of Motors	Propellant Mass (lb)	Insulator mass (lb)	Motor case mass (lb)
C4 F/S	440	38950	500	1690
C4 S/S	410	17450	256	712
C4 T/S	410	3750	5	127

Table 2
D5 Motor Inventory for Disposal

Motor Type	Number of Motors	Propellant Mass (lb)	Insulator mass (lb)	Motor case mass (lb)
D5 F/S	230	81540	1165	1800
D5 S/S	230	24500	420	424
D5 T/S	230	4700	91	68

Description and Discussion of the LM Contained Burn Facility for Fleet Ballistic Solid Rocket Motors

The contained burn facility features three firing chambers, one for each stage of C4. These firing chambers are designed to function under the maximum operating conditions expected from the low pressure combustion of the motors, Table 3. Two parallel particulate and acid gas treatment modules are connected to all three firing chambers. The equipment for one of these modules is designed for the treatment of C4 S/S combustion products while the other for the treatment of C4 T/S combustion products. Both treatment modules are used for the treatment of C4 F/S combustion products and are sized to remove gas and particulate based on the maximum sustained mass flow, Table 4.

Table 3
Firing Chamber Operation Specifications

Specifications	NAC	PTC
Chamber pressure (psia)	2	30
Exit temperature (F)	500	1000
Percentage of propellant mass burned during NAC & PTC	17	83

Motors are loaded and secured onto a cradle, the cradle is moved into the firing chamber, the firing chamber is closed, and the motor is ignited using a standard ignitor. Solid rocket motors containing Class 1.1 propellant and burned at low pressure exhibit non-steady state conditions, Figure 3. The combustion profile is roughly characterized as bi-modal. Subsequent to motor ignition the propellant burn rate is low and the motor pressure is near ambient, coined Near Ambient Combustion (NAC). During NAC the aluminum in the propellant has not gained sufficient heat to sustain combustion and is ejected from the motor partially reacted. The motor output is low and the efficiency of the combustion is poor. As the motor combustion process progresses, the oxidation reaction of the aluminum continues to increase until the motor transitions to a higher output phase coined Post Transition Combustion (PTC). PTC burn rate is almost twice that observed for near ambient combustion, and the pressure time curve closely follows the mass flow time curve shown in Figure 3. Despite the bi-modal burn rate observed in the ambient combustion of Class 1.1 solid rocket motors, the variation between pressure time curves of three C4 S/S contained burn test is small, Figure 4. Over approximately a 20 minute period following propellant combustion, motor insulation and 10% of the motor case are consumed.

The temperature of the combustion products is moderated by injecting water into the combustion gas stream

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Table 4
Calculated Gas and Solids Mass Flow Rates for C4 and D5
Motors under PTC and NAC

Post Transition Combustion (PTC)					
Motor	Ab (in ²)	wt, % Al, in propel- lant	Total flow rate (lb/sec)	Gas (lb/sec)	Solids (lb/sec)
C4 F/S	20000	19	185	119	66
C4 S/S	9000	19	75	47	28
C4 T/S	4900	19	45	29	16
D5 F/S	36500	18	335	221	114
D5 S/S	11800	18	97	64	33
D5 T/S	5700	19	52	33	19
Near Ambient Combustion (NAC)					
Motor	Ab (in ²)	wt, % Al, in propel- lant	Total flow rate (lb/sec)	Gas (lb/sec)	Solids (lb/sec)
C4 F/S	20000	19	65	47	18
C4 S/S	9000	19	29	21	8
C4 T/S	4900	19	16	12	4
D5 F/S	36500	18	119	88	31
D5 S/S	11800	18	38	28	10
D5 T/S	5700	19	19	13	5
Ab = propellant burn surface area					

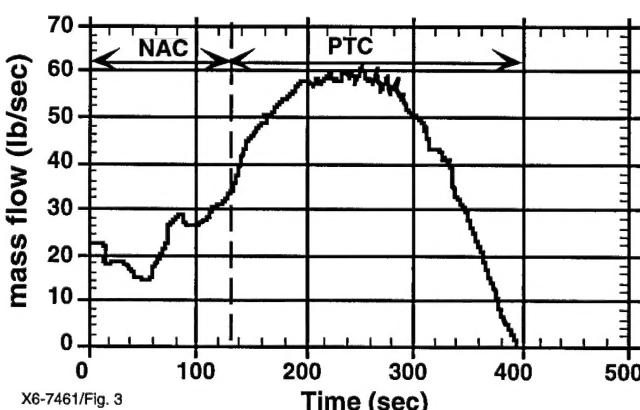


Figure 3 Near Ambient and Post Transition Mass Flow Characteristics of a Contained Burn Fixed SRM

using a high pressure water quench system. The temperature is lowered sufficiently to meet the operating requirements of

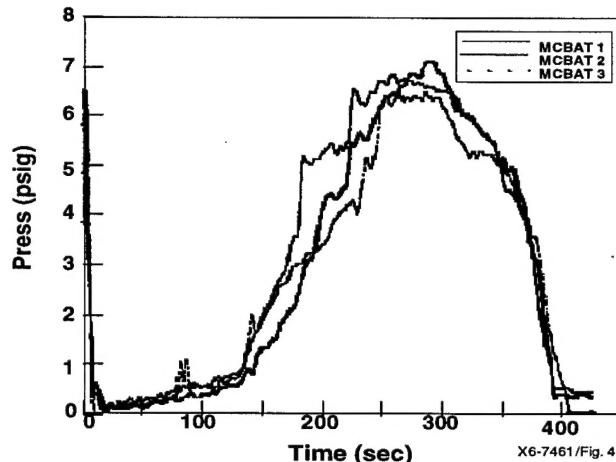


Figure 4 Pressure time curve of three C4 S/S motors fired in Scrubber Modified Contain Burn Assessment Test

gas transfer ducting that runs between the firing chamber and the inlet of the particulate treatment module.

The bi-modal burn rate nature of Class 1.1 propellants has a significant impact on the design of the treatment system. The treatment system has to be able to efficiently scrub combustion gas and solid products over a wide range of mass flow rates, Table 4, and chemical compositions, Tables 5 and 6. For this reason the particulate treatment module uses a variable throat venturi scrubber. The cooled rocket motor combustion products enter the particulate scrubber from above and travel downwards. Dilute caustic droplets are sprayed

Table 5
Near Ambient and Post Transition Combustion
Gas Composition

Compound	NAC (mole %)	PTC (mole %)
Hydrogen	26	34
Carbon Monoxide	22	25
Carbon Dioxide	15	13
Water	10	3.0
Nitrogen	23	21
Nitric Oxide	0.11	0.04
Methane	0.25	0.16
Ethylene	0.002	0.001
Acetylene	0.27	0.23
Hydrogen Cyanide	0.005	0.005
Hydrogen Chloride	3.0	2.7

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Table 6
Motor Insulation/Chamber Combustion
Gas Composition

Gas	wt. %
H ₂	4.39
CO	48.28
CO ₂	46.00
CH ₄	0.32
C ₂ H ₂	0.07
Volatile & semi-volatile organics	0.56
HCN	0.38
Sum	100

concurrently into the particulate laden gas using a series of nozzles and the mixture flows through a multiplicity of variable throat venturis. The particulate accelerate as they travel through the section and are intercepted by the large caustic droplets. The particulate which now have a larger effective diameter and thus settling velocity fall out of the gas stream and are collected in the scrubber caustic tank located below the venturi scrubber. Use of self-adjusting variable venturis ensures that particulate removal efficiency remains constant despite variable incoming mass flow rates.

The gas stream, free of particulate enters the caustic scrubber for acid gases. The primary acid gas components of the combustion gas stream are hydrochloric acid and hydrogen cyanide. Acid gases are efficiently removed from the stream using a scrubbing liquor of sodium hydroxide. The caustic solution flows counter-current to the combustion gas stream increasing the effective mixing of the combustion gas and the caustic solution resulting in complete neutralization of the acid gases. The gas stream now devoid of the acid gases passes through a demister to remove and recover entrained water before it enters the thermal oxidation unit where carbon monoxide and organic material are oxidized to carbon dioxide and water. Efficient removal of water by the demisters reduces the amount of fuel required to operate the thermal oxidation system. Demonstrated removal efficiencies for the acid gases and solids is high and above design specifications, Table 7. The trace chemical composition of the scrubbed solids is displayed in Table 8. Primary destruction of organic chemical species is from motor combustion, Table 9. Organic chemical species that remain after, or form as a result of combustion, are either captured in the treatment solutions or are thermally oxidized by the thermal oxidation unit at the exit of the gas treatment system.

Processing fluids, along with the residual cooling water from the firing chamber, are cleansed through the process

Table 7
Removal Efficiency of the Firing Chamber and Scrubbing
Systems in the Contained Burn Process

Component	Total Removal (%)	Found in Firing Chamber (%)	Found in Particulate Scrubber (%)	Found in Acid Gas Scrubber (%)
Hydrogen Chloride	99.0	33.0	43.0	23.0
Hydrogen Cyanide	99.0	0.2	18.0	80.8
Particulate	98.8	16.5	82.3	0.0

water treatment system allowing much of the water used in the process to be recycled. Process fluids containing chemical combustion products, primarily solids, cool as they flow to the clarifier. Hypochlorite oxidation of cyanide ions is effected in the clarifier. The underflow of the clarifier, enriched with solids, passes to a filter press from which a 65 weight percent solids cake is produced. The major solid product of the contained burn process, aluminum oxide, is recovered from the filter press for recycling. Over 80% of the liquid overflow from the clarifier is recycled for use during the next disposition operation. The remainder of the overflow is pH adjusted and then transferred to a sulphate co-precipitation and filtration process to remove dissolved heavy metals. It is then checked for industrial waste discharge compliance and discharged to the sewer.

Conclusion

Lockheed Martin's conceptual design for a contained burn facility capable of the safe disposition of solid rocket motors containing Class 1.1 propellant is a cost effective, well developed, and environmentally responsible technology. The full scale prototype facility demonstrated: 1) the efficacy of low pressure combustion of 20,000 pounds of Class 1.1 propellant in a contained firing chamber, 2) a water quench system capable of cooling the combustion gases to 800°F, 3) the efficient removal of micron size aluminum oxide particulate and the acid gases, hydrogen chloride and hydrogen cyanide, and 4) high destruction efficiency of organic chemical species. This test series also provided the engineering data required to size the thermal oxidation system for carbon monoxide and organic destruction, the solids concentration and recovery system for aluminum oxide, and the sulfate co-precipitation and filtration system. This conceptual design is

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Table 8
Firing Chamber and Scrubber Particulate chemical composition

Compounds	Firing chamber	Particulate scrubber
Zinc (mg/kg)	5245	727
Other heavy metals (mg/kg)	1335	36
Volatile and Semi-volatile organics (ug/kg)	6902	1651

based on the safe and reliable operation of 14 full scale contained burn solid rocket motor tests and over 40 sub-scale tests.

Acknowledgments:

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Table 9

Relative Masses of Volatile and Semi-volatile Organics Produced during Propellant Combustion and Case & Insulator Smoldering

Chemical Species	From Propellant Burn (lb/1000 lb)	From Case & Insulator (lb/100 lb)
Volatile organic		
chloromethane	'	0.027
other chlorinated hydrocarbons		0.042
benzene	0.092	0.094
1,2-dichloroethane	0.021	
Volatile Organic Sum	0.113	0.163
Semi-volatile		
other chlorinated hydrocarbons		0.0003
toluene	0.001	
chlorobenzenes	0.002	
other aromatic hydrocarbons		0.005
o/m/p/ xylene	0.003	0.008
chlorinated PAH	0.002	0.010
chlorinated aromatics		0.003
phenol		0.0006
phenol, methyl-substituted phenols	0.002	0.006
naphthalenes	0.0005	0.0004
hydrocarbons	0.050	0.077
other short chain hydrocarbons		0.002
Semi-volatile sum	0.0605	0.1123
Sum Total	0.1735	0.2753
PAH = PolyAromatic Hydrocarbons		

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